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Lunar Reconnaissance Orbiter Project

Spacecraft/Orbiter Performance Assurance Implementation Plan

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National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

CM FOREWORD

This document is a Lunar Reconnaissance Orbiter (LRO) Project Configuration Management (CM)-controlled document. Changes to this document require prior approval of the applicable Configuration Control Board (CCB) Chairperson or designee. Proposed changes shall be submitted to the LRO CM Office (CMO), along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

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LUNAR RECONNAISSANCE ORBITER PROJECT

DOCUMENT CHANGE RECORD

Sheet: 1 of 1

REV LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED
Rev -	Released per 431-CCR-000015	C. Tooley	9/27/2005

List of TBDs/TBRs

Item No.	Location	Summary	Ind./Org.	Due Date
1	Section 9.6	Obtain CM-Controlled Document Number for the LRO Orbiter Transportation, Handling, and Storage Specification to replace TBD in this document	J. Baker/ GSFC	12/31/2005

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1.0 OVERALL IMPLEMENTATION

1.1 DESCRIPTION OF OVERALL IMPLEMENTATION

The requirements of the Lunar Reconnaissance Orbiter Mission Assurance Requirements (431-RQMT-000174) document will be implemented in accordance with this Lunar Reconnaissance Orbiter Spacecraft Performance Assurance Implementation Plan (PAIP). Unless specifically addressed within this plan, the scope of application of this plan to flight and ground system hardware and software is commensurate with the defined scope of application of the performance assurance requirements in the Lunar Reconnaissance Orbiter Mission Assurance Requirements (431-RQMT-000174) document.

1.1.1 Assurance Management Implementation

Responsibility for the application of this PAIP rests with all LRO project members and, ultimately, the LRO Project Manager. Responsibility for the management of performance and safety assurance activities described in the PAIP rests with the LRO Systems Assurance Manager (SAM).

The primary responsibility of the SAM is to ensure the products produced by the Spacecraft Developer (GSFC) intended for design qualification, flight and critical ground support equipment (GSE) usage meet the required levels of quality, reliability, safety and functionality for their intended purposes. The SAM shall be delegated the authority and responsibility to accomplish the following:

a. Participate in procurement activities from statement of work through final delivery

b. Establish and implement quality and safety assurance requirements

c. Perform internal, partner, and supplier technical risk assessment, process assessment and product evaluation

d. Assist the LRO Project in tailoring the software/hardware development processes

e. Review and/or approve technical documents related to hardware/software, including equipment specifications, procurement, software system requirement, assembly procedures, test procedures and payload integration procedures

f. Oversee and assess critical supplier operations

g. Assist in metrics definition and assure that the development team is following the defined processes

h. Assure the identification, implementation, and verification of safety-critical components are performed

i. Document and communicate quality status/problems and recommend preventative/corrective action.

1.2 USE OF MULTI-MISSION OR PREVIOUSLY DESIGNED, FABRICATED, OR FLOWN HARDWARE

When hardware that was designed, fabricated, or flown on a previous project is considered to have demonstrated compliance with all of the requirements of this document such that certain tasks need not be repeated, LRO shall demonstrate how the hardware complies with requirements prior to being relieved from performing any tasks. All use of heritage hardware shall be verified for use in its application on LRO. The verification shall take into account necessary design modifications, changes to expected environments and differences in operational use. Data Item Description (DID) 1-1 of the Lunar Reconnaissance Orbiter Mission Assurance Requirements (431-RQMT-000174) defines the required matrix detailing all the required information for consideration.

1.3 SURVEILLANCE

The work activities, operations, and documentation performed by the GSFC or their suppliers are subject to evaluation, review, audit, and inspection by government-designated representatives from the LRO Project Office, a Government Inspection Agency (GIA), or an independent assurance contractor (IAC). The LRO Project Office may delegate in-plant responsibilities and authority to those agencies via a letter of delegation, or a GSFC contract with an IAC.

LRO project assurance representatives will maintain documents, records, and equipment required to perform their assurance and safety activities. The LRO Project will also provide the assurance representative(s) with an acceptable work area.

1.4 ACRONYMS AND GLOSSARY

The LRO PAIP and the definitions included in implementing documents referenced herein define acronyms and terms as applied in this plan. (See Appendix B for Abbreviations and Acronyms.)

1.5 CONTRACT DELIVERY REQUIREMENTS LIST

The Contract Delivery Requirements List (CDRL) contains DIDs which describe data deliverable to the LRO Project Office. (See Appendix A for CDRL and DIDs) The “CDRL numbers” cited in this document refer to the “CDRL numbers” listed on the DIDs contained in the CDRL. Performance assurance deliverables required from project contractors are defined in appropriate contract procurement packages and any required contractor assurance implementation plans.

Unless otherwise indicated in this plan, all required documentation generated for the Spacecraft shall be provided to the LRO Project Office by the responsible project personnel as scheduled in applicable CDRL DID. Contractor-provided assurance deliverables shall be provided upon receipt by the contract Technical Representative to the LRO Project Office. The SAM shall provide review comments or approval/disapproval recommendations as appropriate to the LRO Project Manager on all assurance deliverables received for project review or approval.

1.6 REQUIREMENTS DOCUMENTS

All Spacecraft prepared requirements documents such as the spacecraft specification, the spacecraft performance verification plan, and associated documentation such as the Risk Management Plan and System Safety Program Plan will be delivered electronically to the LRO Project Office for analysis and comments or approval.

2.0 QUALITY ASSURANCE REQUIREMENTS

2.1 GENERAL REQUIREMENTS

The Spacecraft Developer and its contractors shall define and implement a Quality Management System (QMS) that is based on American National Standards Institute (ANSI)/American Society for Quality Control (ASQC) Q9001-2000, Quality Systems – Model for Quality Assurance in Design, Development, Production, Installation, and Servicing, that properly encompasses the Spacecraft Developer's flight hardware and software.

The LRO Project Office intends to allow contractors to use their own ANSI/ASQC Q9001 compliant system and procedures to the fullest extent possible, provided the requirements of this PAIP and the associated CDRL DIDs are satisfied.

The International Standards Organization (ISO) 9001 Quality Standard specifies requirements which determine what elements quality systems have to encompass, but it allows significant flexibility in determining which requirements actually apply and how they are implemented. It is intended that the use of the ISO 9001 Quality Standard will also allow the Spacecraft Developer to concentrate on value-added quality activities. The Developer's Quality Manual will be provided in accordance with CDRL, DID 2-1.

2.2 QUALITY ASSURANCE MANAGEMENT SYSTEM REQUIREMENTS AUGMENTATION

The following requirements augment the identified portions of ANSI/ASQC Q9001-2000.

Section 4.4.4:

New on-orbit design of software and ground stations hardware shall be in accordance with original system design specifications and validation processes.

Section 4.6.3:

The supplier's Quality Assurance (QA) program should ensure flow-down to all major and critical suppliers of technical requirements and a process to verify compliance i.e., matrix or related documentation.

Section 4.13.2:

The reporting of failures will begin with the first power application at the lowest level of assembly or the first operation of a mechanical item. It will continue through formal acceptance by the LRO Project Office.

Failures shall be reported to the LRO Project Office within 24 hours of occurrence (initial report). (Refer to the CDRL, 2-2)

The final failure documentation provided to LRO will include Material Review Board (MRB)/Failure Review Board (FRB) minutes and reports.

The Spacecraft Developer's review/disposition/approval of failure reports will be described in the applicable procedure(s).

2.3 QUALITY ASSURANCE ACTIVITIES AT GSFC

The LRO Project SAM shall assign hardware QA engineers to oversee the design, procurement, fabrication, assembly and testing of all flight hardware. Software quality engineers assigned to the project will perform similar functions on all software related to flight and critical ground systems.

The GSFC Quality Manual (GPR 9730.3) and associated Goddard Procedural Requirements (GPR) under the Goddard Directives Management System (GDMS) defines the controls and practices in place at GSFC which shall be adhered to for the LRO Project. Any deviations form these directives must be approved by the LRO SAM before used on flight hardware.

3.0 SYSTEM SAFETY REQUIREMENTS

3.1 SYSTEM SAFETY REQUIREMENTS

The Spacecraft Developer will prepare a System Safety Program Plan (SSPP) (Refer to CDRL, 3-1) which will define the safety program in effect during all stages of design, development, fabrication, and test on the LRO Spacecraft. The LRO Systems Safety Program is intended to ensure safety of personnel, flight hardware, support facilities, and equipment during ground and flight operations from all hazards. The SSPP describes the safety management and engineering activities that ensures identification of hazards and, where possible, elimination or control of these hazards.

The LRO Systems Safety Program will be in accordance with the following top level safety requirements documents. The activities of the safety program are intended to meet the requirements of these documents to the extent that it is applicable to the Spacecraft development.

a. Air Force Space Command Manual (AFSCM) 91-710, “Range Safety User Requirements Manual,” which defines the Range Safety Program responsibilities and authorities and which delineates policies, processes, and approvals for all activities from the design concept through test, check-out, assembly, and the launch of launch vehicles and payloads to orbital insertion or impact from or onto the Eastern Range (ER) or the Western Range (WR). It also establishes minimum design, test, inspection, and data requirements for hazardous and safety critical launch vehicles, payloads, and ground support equipment, systems, and materials for ER/WR users.

b. KHB 1710.2, “Kennedy Space Center (KSC) Safety Practices Handbook,” which specifies and establishes safety policies and requirements essential during design, operation, and maintenance activities at KSC and other areas where KSC has jurisdiction.

As appropriate, any testing performed at GSFC must comply with the safety requirements contained in 5405-048-98, the Mechanical Systems Center Safety Manual.

Satisfactory compliance with the above requirements is required to gain payload access to the launch site and the subsequent launch. The LRO Project Manager ensures compliance with the requirements and will certify to the launch range that all of the requirements have been met.

The Spacecraft Developer will participate in Project activities associated with compliance to NASA Policy Directive for Limiting Orbital Debris Generation (NPD 8710.3). Design and safety activities will take into account the instrument’s impact on the spacecraft’s ability to conform to debris generation requirements.

3.2 GROUND OPERATIONS PLAN INPUTS

The Spacecraft Developer will provide Ground Operations Plan inputs to the LRO Project. These inputs include a detailed description of hazardous and safety critical operations for processing aerospace systems and their associated GSE.

This information is essential to the mission ground operations plan and is the medium through which missile Pre-Launch safety approval is obtained. The initial draft of this information is required to be delivered to LRO Project Safety Manager at Critical Design Review (CDR) with the final version due 45 days prior to the Spacecraft Pre-Shipment Review (PSR). (Refer to CDRL 3-2)

3.3 SYSTEM SAFETY DELIVERABLES

Refer to the CDRL 3-1 through 3-10 for the System Safety deliverables.

4.0 RELIABILITY REQUIREMENTS

4.1 GENERAL REQUIREMENTS

The Spacecraft Developer will plan and implement a reliability program that interacts effectively with other project disciplines, including systems engineering, hardware design, and product assurance. The program will be tailored according to the risk level to:

a. Demonstrate that redundant functions, including alternative paths and work-arounds, are independent to the extent practicable.

b. Demonstrate that the stress applied to parts is within its derating guidelines and is not excessive.

c. Identify single failure items/points, their effect on the attainment of mission objectives, and possible safety degradation.

d. Single point failures that inhibit the ability to fully meet mission success requirements shall be identified and the risk associated with it shall be characterized, tracked and managed.

e. Show that the reliability design aligns with mission design life and is consistent among the systems, subsystems, and components.

f. Identify limited-life items and ensure that special precautions are taken to conserve their useful life for on-orbit operations.

g. Select significant engineering parameters for the performance of trend analysis to identify performance trends during pre-launch activities.

h. Ensure that the design permits easy replacement of parts and components and redundant paths are easily monitored.

4.2 RELIABILITY ANALYSIS

Reliability analyses will be performed so that identified problem areas can be addressed and correction action taken (if required) in a timely manner.

4.2.1 Failure Modes and Effects Analysis and Critical Items List

A Failure Modes and Effects Analysis (FMEA) will be performed early in the design phase to identify system design problems. As additional design information becomes available the FMEA will be refined.

Failure modes will be assessed at the component interface level. Each failure mode will be assessed for the effect at that level of analysis, the next higher level and upward. The failure mode will be assigned a severity category based on the most severe effect caused by a failure.

Mission phases (e.g., launch, deployment, on-orbit operation, and retrieval) will be addressed in the analysis.

Severity categories will be determined in accordance with Table 4-1:

Table 4-1. Category Severity Definition

Category	Definition
1	Catastrophic Failure modes that could result in serious injury, loss of life (flight or ground personnel), or loss of launch vehicle.
1R	Failure modes of identical or equivalent redundant hardware items that, if all failed, could result in category 1 effects.
1S	Failure in a safety or hazard monitoring system that could cause the system to fail to detect a hazardous condition or fail to operate during such condition and lead to Severity Category 1 consequences.
2	Critical Failure modes that could result in loss of one or more mission objectives as defined by the GSFC project office.
2R	Failure modes of identical or equivalent redundant hardware items that could result in Category 2 effects if all failed.
3	Significant Failure modes that could cause degradation to mission objectives.
4	Minor Failure modes that could result in insignificant or no loss to mission objectives

FMEA analysis procedures and documentation will be performed in accordance with documented procedures. Failure modes resulting in Severity Categories 1, 1R, 1S or 2 will be analyzed at a greater depth, to the single parts if necessary, to identify the cause of failure.

Results of the FMEA will be used to evaluate the design relative to requirements. Identified discrepancies will be evaluated by management and design groups for assessment of the need for corrective action.

The FMEA will analyze redundancies to ensure that redundant paths are isolated or protected such that any single failure that causes the loss of a functional path will not affect the other functional path(s) or the capability to switch operation to that redundant path.

All failure modes that are assigned to Severity Categories 1, 1R, 1S and 2, will be itemized on a Critical Items List (CIL) and maintained with the FMEA report. (Refer to the CDRL 4-3)

Rationale for retaining the items will be included on the CIL. The FMEA and CIL will be provided to the LRO Project Office for review and/or audit. Results of the FMEA and implementation plan as well as the CIL will be presented at all design reviews starting with the Preliminary Design Review (PDR). The presentations will include comments on how the analysis was used to perform design trade-offs or how the results were taken into consideration when making design or risk management decisions.

4.2.2 Parts Stress Analysis

Each application of electrical, electronic, and electromechanical (EEE) parts, will be subjected to stress analyses for conformance with the applicable derating guidelines (Refer to Lunar Reconnaissance Orbiter Mission Assurance Requirements (431-RQMT-000174, Section 4.4.3). The analyses will be performed at the most stressful values that result from specified performance and environmental requirements (e.g., temperature and voltage) on the assembly or component. The analyses will be performed in close coordination with the packaging reviews and thermal analyses and they will be required input data for component-level design reviews. (Refer to Lunar Reconnaissance Orbiter Mission Assurance Requirements (431-RQMT-000174, Section 8.2.) The analyses will be maintained by the Spacecraft Developer for the LRO Project Office to review/audit. The results of the analyses will be presented at all design reviews starting with the PDR. The presentations will include comments on how the analysis was used to perform design trade-offs or how the results were taken into consideration when making design or risk management decisions.

4.2.3 Worst Case Analysis

Worst Case Analyses may be performed on circuits where failure results in a severity category of 2 or higher question the flightworthiness of the design. If performed, the most sensitive design parameters, including those that are subject to variations that could degrade performance, will be subjected to the analysis. The adequacy of design margins in the electronic circuits, optics, electromechanical, and mechanical items will be demonstrated by analyses or test or both to ensure flightworthiness. This analysis will be made available by the Spacecraft Developer for LRO Project Office review. The results of any analyses and risk mitigation plan will be presented at all design reviews starting with the PDR. The presentations will include comments on how the analysis was used to perform design trade-offs or how the results were taken into consideration when making design or risk management decisions.

The analyses will consider all parameters set at worst case limits and worst case environmental stresses for the parameter or operation being evaluated. Depending on mission parameters and parts selection methods, part parameter values for the analysis will typically include: manufacturing variability, variability due to temperature, aging effects of environment, and variability due to cumulative radiation. The analyses and updates will be made available to LRO Project Office for information prior to manufacturing of flight hardware.

4.2.4 Reliability Assessments

When necessary/prudent or when agreed-upon with the LRO Project Office, the Spacecraft Developer will perform comparative numerical reliability assessments to:

a. Evaluate alternative design concepts, redundancy and cross-strapping approaches, and part substitutions

b. Identify the elements of the design which are the greatest detractors of system reliability

c. Identify those potential mission limiting elements and components that will require special attention in part selection, testing, environmental isolation, and/or special operations

d. Assist in evaluating the ability of the design to achieve the mission life requirement and other reliability goals and requirements as applicable

e. Evaluate the impact of proposed engineering change and waiver requests on reliability

Reliability assessments will be integrated with the design process and other assurance practices to maximize the probability of meeting mission success criteria. The Spacecraft Developer will consider how the reliability assessments will incorporate definitions of failure as well as alternate and degraded operating modes that describe plausible acceptable and unacceptable levels of performance. Degraded operating modes will include failure conditions that could be alleviated or reduced significantly through the implementation of work-arounds via telemetry.

The assessments and updates will be submitted to the LRO Project Office for information. The results of any reliability assessment will be reported at PDR and CDR. The presentations will include comments on how the analysis was used to perform design trade-offs or how the results were taken into consideration when making design or risk management decisions.

4.3 ANALYSIS OF TEST DATA

The Spacecraft Developer will fully utilize test information during the normal test program to assess flight equipment reliability performance and identify potential or existing problem areas.

4.3.1 Trend Analysis

As part of the routine system assessment, the Spacecraft Developer shall assess subsystems and components to determine measurable parameters that relate to performance stability. Selected parameters shall be monitored for trends starting at component acceptance testing and continuing during the system integration and test phases. The monitoring will be accomplished within the normal test framework; i.e., during functional tests, environmental tests, etc. The Spacecraft Developer shall establish a system for recording and analyzing the parameters as well as any changes from the nominal even if the levels are within specified limits. Trend analysis data shall be reviewed with the operational personnel prior to launch, and the operational personnel shall continue recording trends throughout mission life. A list of subsystem and components to be assessed and the parameters to be monitored and the trend analysis reports will be maintained.

4.3.2 Analysis of Test Results

The Spacecraft Developer will analyze test information, trend data, and failure investigations to evaluate reliability implications. Identified problem areas shall be documented and directed to the attention of LRO Project Management for action. The results of the analyses will be presented at design reviews. The presentations will include comments on how the analysis was used to perform design trade-offs or how the results were taken into consideration when making design or risk management decisions.

4.4 LIMITED LIFE ITEMS

Limited-life items will be identified and managed by means of a Limited-Life List, which will be submitted for approval. (Refer to the CDRL 4-9) The list will present definitions, the impact on mission parameters, responsibilities, and a list of limited-life items, including data elements: expected life, required life, duty cycle, and rationale for selection. The useful life period starts with fabrication and ends with the completion of the final orbital mission.

The list of limited-life items should include selected structures, thermal control surfaces, solar arrays and electromechanical mechanisms. Atomic oxygen, solar radiation, shelf-life, extreme temperatures, thermal cycling, wear and fatigue should be used to identify limited-life thermal control surfaces and structure items. All mechanisms such as batteries, compressors, seals, bearings, valves, recorders, momentum wheels, gyros, actuators, and scan devices should be included when aging, wear, fatigue and lubricant degradation limit their life. Records shall be maintained that allow evaluation of the cumulative stress (time and/or cycles) for limited-life items starting when useful life is initiated and indicating the project activity that will stress the items. The use of an item whose expected life is less than its mission design life must be approved by the LRO Project Office by means of a program waiver.

4.5 RELIABILITY DELIVERABLES

Refer to CDRLs 4-1 through 4-9 for the Reliability deliverables.

5.0 SOFTWARE ASSURANCE REQUIREMENTS

5.1 GENERAL

The Spacecraft Developer shall employ a structured program (Software Quality Management System [SWMS]) for the development of software**.** The program shall recognize the phases of the development life cycle (requirements analysis, design, code and unit test, integration and build test, performance verification, and maintenance) and utilize appropriate mechanisms to facilitate the development effort and ensure the quality of the product. These mechanisms include documentation, reviews, verification activities, and configuration management. The program shall encompass Spacecraft flight software and firmware, ground test equipment software, and any software related to mission operations. Science and data analysis software are excluded from these requirements.

5.2 SOFTWARE QUALITY MANAGEMENT SYSTEM

The Spacecraft Developer's SQMS will be based on the ANSI/ASQC Q9001 Quality Standard. The following activities augment the identified portions of ANSI/ISO/ASQ Q9000-3, which provides guidance on the development of a SQMS that is based on ANSI/ASQC Q9001.

5.2.1 Reviews (Augmentation to Section 4.1.3, ANSI/ASQC Q9000-3)

There will be a series of Spacecraft Developer-presented formal reviews conducted by a GSFC-chaired review panel that will include independent experts in the type of software under review. The formal reviews will consist of, as a minimum, a PDR, a Systems Requirements Review (SRR), a CDR, a Test Readiness Review (TRR), and an Acceptance Review (AR). These reviews will be coordinated with the reviews defined in Section 8. The Spacecraft Developer will record minutes and action items during each review.

5.2.2 Corrective Action (Augmentation to Section 4.1, ANSI/ASQC Q9000-3)

The corrective action process will start at the establishment of a configuration management baseline that includes the product. The use of the formal software corrective action process will become mandatory with the first instance of the software's delivery to testing for the verification software requirements. GSFC personnel will be allowed access to problem reports and corrective action information, as they are prepared.

5.2.3 Configuration Management (Augmentation to Section 4.8, ANSI/ASQC Q9000-3)

The developer shall develop and implement a Software Configuration Management (SCM) system that provides baseline management and control of software requirements, source code, data, and documentation. The developer shall document the SCM system.

The Spacecraft Developers SCM system will have a change classification and impact assessment process that results in Class 1 changes being forwarded to the LRO Project Office for disposition. Class 1 changes are defined as those, which affect system requirements, software requirements, system safety, reliability, cost, schedule, and external interfaces.

5.2.4 Inspection, Testing and Verification Matrix (Augmentation to Section 4.10.4, ANSI/ASQC Q9000-3)

As part of the Spacecraft Developer's effort to verify to the Government that their software is flight worthy, the Spacecraft Developer shall prepare and maintain a software performance verification matrix. When the document is prepared, an up-to date version will be provided to the LRO Project Office. If a matrix is prepared, as a minimum, it will include:

a. How each specification requirement will be verified

b. The reference source (to the specific paragraph or line item)

c. The method of compliance

d. The applicable procedure references

e. Verification results

f. Report reference numbers

5.2.5 Final Configuration Audit and Verification (Augmentation to Section 4.10.4, ANSI/ASQC Q9000-3)

As part of the Spacecraft Developer's effort to verify to the LRO Project Office that their software is flight worthy, the Spacecraft Developer and the LRO Project Office shall conduct a Functional Configuration Audit (FCA) and Physical Configuration Audit (PCA) on the final delivered product and on major upgrades (defined as the change of 20% or more of the lines of code) to that product upon their mutual agreement. The Spacecraft Developer will provide the results of any audit(s) to the LRO Project Office.

5.3 GFE, EXISTING AND PURCHASED SOFTWARE

If software will be provided to the Spacecraft Developer as government-furnished equipment (GFE) or if the Spacecraft Developer will use existing or purchased software; the Spacecraft Developer is responsible for the software meeting the functional, performance, and interface requirements placed upon it. The Spacecraft Developer is also responsible for ensuring that the software meets all applicable standards, including those for design, code, and documentation; or for securing a project waiver to those standards. Any significant modification to any piece of the existing software will be subject to all of the provisions of the Spacecraft Developer's SQMS and the provisions of this document. A significant modification is defined as the change of twenty percent of the lines of code in the software.

5.4 SOFTWARE SAFETY

If any software component is identified as safety critical, the Spacecraft Developer will conduct a software safety program on that component that complies with NASA-STD-8719.13, "Software Safety Standard."

5.5 INDEPENDENT VERIFICATION AND VALIDATION

The Spacecraft Developer will provide all information required for the NASA IV&V effort to the Independent Verification and Validation (IV&V) personnel. The developer will provide electronic access to the required information or provide a soft copy of the requested information. The developer will review the IV&V findings and recommendations and forward the project assessment of these findings to the IV&V personnel. The developer will take necessary corrective action based upon their assessment and notify IV&V of this action.

5.6 STATUS REPORTING

The Spacecraft Developer shall provide status reports to the LRO Project Office to provide management insight into software development progress, issues, problems, actions taken, and schedules. This information shall be included in the Spacecraft Developer's Progress Reports to the Project or it shall be presented at the monthly or quarterly status reviews.

5.7 SOFTWARE ASSURANCE DELIVERABLES

Refer to CDRL 5-1 through 5-5 for Software Assurance deliverables.

6.0 GROUND DATA SYSTEM REQUIREMENTS

6.1 SPACECRAFT DEVELOPER RESPONSIBILITIES

The Spacecraft Developer will coordinate all ground system interfaces with the project Ground Data Systems (GDS) requirements documentation. Documented verification of testing and compatibility of interfaces will be made available for LRO review prior to any flight hardware integration and test (I&T).

7.0 RISK MANAGEMENT REQUIREMENTS

7.1 GENERAL REQUIREMENTS

The Spacecraft Developer will develop and implement a project-specific Risk Management Plan as a means to anticipate, mitigate and control risks and to focus project resources where they are needed to ensure success of the project. The NPR 7120.5, NASA Program and Project Management Processes and Requirements, is the controlling requirements/guideline used in the preparation of this plan. (Refer to CDRL 7-1) NPR 8000.4, Risk Management Procedures and Guidelines is a valuable asset for establishing a risk management process.

The primary activities of the Spacecraft Developer Continuous Risk Management process are:

a. Search for, locate, identify, and document reliability and quality risks before they become problems

b. Evaluate, classify, and prioritize all identified reliability and quality risks

c. Develop and implement risk mitigation strategies, actions, and tasks and assign appropriate resources.

d. Track risk being mitigated; capture risk attributes and mitigation information by collecting data; establish performance metrics; and examine trends, deviations, and anomalies

e. Control risks by performing: risk close-out, re-planning, contingency planning, or continued tracking and execution of the current plan

f. Communicate and document (via the risk recording, reporting, and monitoring system) risk information to ensure it is conveyed between all levels of the project

g. Report on outstanding risk items at all management and design reviews.

The LRO Project Office, the GSFC Systems Review Office (SRO) (for design reviews only), and the Spacecraft Developer will agree on what level of detail is appropriate for each review.

All identified reliability and quality risks will be documented, updated and reported in accordance with the Spacecraft Developer's Risk Management Plan. Although not all risks will be fully mitigated, all risks shall be addressed with mitigation and acceptance strategies agreed upon at appropriate mission reviews.

7.2 PROBABALISTIC RISK ASSESSMENT

The Spacecraft Developer shall provide all requested/required information to LRO so that the LRO Project Office can perform a Probabilistic Risk Assessment (PRA) for their hardware and software. (CDRL 4-2) It shall take into account a Fault Tree Analysis (FTA) (CDRL 4-4) which the LRO Project Office will also prepare with information provided by the Spacecraft Developer.

The information required will include parts lists (CDRLs 12-1 and 12-2) and schematics. Additionally, the Spacecraft Developer will cooperate with the LRO Project Office as required to prepare these documents.

7.3 RISK ASSESSMENT

The Spacecraft Developer will provide all requested/required information to the LRO Project Office so that the LRO Project Office can perform an on-going risk assessment of the program including flight hardware and software. Additionally, the Spacecraft Developer will cooperate with the LRO Project Office as required to prepare this assessment.

8.0 INTEGRATED INDEPENDENT REVIEW PROGRAM REQUIREMENTS

8.1 GENERAL REQUIREMENTS

The Spacecraft Developer will support a series of comprehensive system-level design reviews that are conducted by the GSFC Systems Review Office (SRO). The reviews will cover all aspects of flight and ground hardware, software, and operations for which the Spacecraft Developer has responsibility.

8.2 GSFC SYSTEM REVIEW REQUIREMENTS

For each system level review, as required by the GSFC SRO and the Mission Assurance Requirements (MAR), the Spacecraft Developer will:

a. Develop and organize material for oral presentation to the Review Team. Copies of the presentation material for GSFC SRO Reviews will be sent electronically to GSFC 10 days prior to the review date.

b. Support splinter review meetings resulting from the major review.

c. Produce written responses to recommendations and action items resulting from the review.

d. Summarize, as appropriate, the results of Spacecraft Developer Reviews at the component and subsystem level.

8.3 GSFC SYSTEM REVIEW PROGRAM

The GSFC Office of Systems Safety and Mission Assurance (OSSMA) System Review Program (SRP) guidelines consists of individual, periodic reviews of all GSFC managed flight missions, flight instruments, flight spacecraft, ground systems which interface with flight hardware, unique flight support equipment, and their associated software including hardware supplied to GSFC managed flight missions.

The Spacecraft Developer will be reviewed by an Integrated Independent Review Team (IIRT) chaired by the GSFC SRO. The planned reviews are:

a. System Requirements Review (SRR) – This review occurs in the latter stages of formulation (midway in the definition phase). This review establishes that, for the current mission system design, requirements have been formally and fully allocated to all independent flight and ground system elements. In doing so, the project justifies readiness to proceed with preliminary design.

b. Preliminary Design Review (PDR)–This review occurs early in the design phase prior to manufacture of engineering hardware and the detail design of associated software. Where applicable, it should include the results of test bedding, breadboard testing, and software prototyping. It should also include the status of the progress in complying with the launch range safety requirements. At PDR, hazards associated with the flight hardware should be identified and documented.

c. Critical Design Review (CDR)–This review occurs after the design has been completed but prior to the start of manufacturing flight components or the coding of software. It will emphasize implementations of design approaches as well as test plans for flight systems including the results of engineering model testing. The Spacecraft Developer shall present the status of the controls for the safety hazards presented in the PDR and the status of all presentations to the launch range.

d. Mission Operations Review (MOR)–This mission-oriented review will normally take place prior to significant integration and test of the flight system and ground system. Its purpose is to review the status of the system components, including the ground system and its operational interface with the flight system. Discussions will include mission integration, test planning and the status of preparations for flight operations.

e. Pre-Environmental Review (PER)–This review occurs prior to the start of environmental testing of the protoflight or flight system. The primary purpose of this review is to establish the readiness of the system for test and evaluate the environmental test plans.

f. Pre-Shipment Review (PSR)–This review will take place prior to shipment of the orbiter to the launch range. The PSR will concentrate on system performance during qualification or acceptance testing.

The Spacecraft Developer is also required to present the status of the tracking of the safety items listed in the validation tracking log, the status of deliverable documents to the launch range and the status of presentations and any subsequent launch range issues or approvals prior to sending flight hardware to the range.

g. Flight Operations Review (FOR)–While all of the previous reviews involve operations, this review will emphasize the final orbital operation plans as well as the compatibility of the flight components with GSE and ground network, including summary results of the network compatibility tests.

h. Launch Readiness Review (LRR)–This review is to assess the overall readiness of the total system to support the flight objectives of the mission. The LRR is usually held at the launch site 2 to 3 days prior to launch.

The time, place and agenda for each of the reviews will be coordinated between the Spacecraft Developer Project Manager and the Review Team Chairman.

8.4 SYSTEM SAFETY

The safety aspects of the systems being reviewed are a normal consideration in the system evaluations conducted by the IIRT. At each appropriate review, the Spacecraft Developer will demonstrate understanding of and compliance with the applicable launch range requirements, list any known noncompliance's and provide justification for any expected waiver conditions. In addition, the Spacecraft Developer will present the results of any safety reviews held with the Eastern or Western Test Range.

8.5 PEER REVIEW REQUIREMENTS

The Spacecraft Developer will implement a program of peer reviews at the component and subsystem levels. The program will, as a minimum, consist of a PDR and a CDR. In addition, packaging reviews will be conducted on all electrical and electromechanical components in the flight system.

The PDR and CDR will evaluate the ability of the component or subsystem to successfully perform its function under operating and environmental conditions during both testing and flight. The results of parts stress analyses and component packaging reviews, including the results of associated tests and analyses, will be discussed at the component PDRs and CDRs.

The packaging reviews will specifically address the following:

a. Placement, mounting, and interconnection of EEE parts on circuit boards or substrates.

b. Structural support and thermal accommodation of the boards and substrates and their interconnections in the component design.

c. Provisions for protection of the parts and ease of inspection.

Spacecraft Developer peer reviews will be conducted by personnel who are not directly responsible for design of the hardware or software under review. The LRO Project Office and SRO will be invited to attend the peer reviews and will be provided 10 working days notification. The results of the reviews will be documented and the documents will be made available for review.

The peer reviews shall have request for action (RFA) item recordation which are reviewed and assigned to appropriate personnel at the end of the reviews. Timely written responses to recommendations and action items resulting from the review are required by the developer team to the LRO Project and System Review offices as outlined in the system review plan.

9.0 DESIGN VERIFICATION REQUIREMENTS

9.1 GENERAL REQUIREMENTS

A system performance verification program documenting the overall verification plan, implementation, and results will be developed by the Spacecraft Developer to ensure that the payload meets the specified mission requirements, and to provide traceability from mission specification requirements to launch and on-orbit capability. The program will consist of a series of functional demonstrations, analytical investigations, physical property measurements, and tests that simulate the environments encountered during handling and transportation, pre-launch, launch, and in-orbit. All prototype or protoflight hardware will undergo qualification to demonstrate compliance with the verification requirements of this section. In addition, all other hardware (flight, follow-on, spare and re-flight as defined in Lunar Reconnaissance Orbiter Mission Assurance Requirements (431-RQMT-000174, Appendix B, “Hardware”) will undergo acceptance in accordance with the verification requirements of this section.

The Verification Program begins with functional testing of sub-assemblies; it continues through functional and environmental testing supported by appropriate analysis, at the subsystem and Spacecraft Developer levels of assembly; the program concludes with end-to-end testing of the entire operational system including the Spacecraft Developer and MOC.

The General Environmental Verification Standard (GEVS) for GSFC Flight Programs and Projects (Refer to Lunar Reconnaissance Orbiter Mission Assurance Requirements [431-RQMT-000174, Section 9.2.2]), will be used as a baseline guide for developing the verification program. Alternative methods may be utilized provided that the net result demonstrates compliance with the intent of the requirements and has been approved by the LRO Project office.

9.2 DOCUMENTATION REQUIREMENTS

The following documentation requirements will be delivered and approved in accordance with the CDRL of the Lunar Reconnaissance Orbiter Mission Assurance Requirements (431-RQMT-000174).

9.2.1 Performance Verification Plan

An Spacecraft performance verification plan (Refer to CDRL 9-1) will be prepared defining the tasks and methods required to determine the ability of the Spacecraft to meet each project-level performance requirement (structural, thermal, optical, electrical, guidance/control, Radio Frequency (RF)/telemetry, science, mission operational, etc.) and to measure specification compliance. Limitations in the ability to verify any performance requirement will be addressed, including the addition of supplemental tests and/or analyses that will be performed and a risk assessment of the inability to verify the requirement. The plan will address how compliance with each specification requirement will be verified. If verification relies on the results of measurements and/or analyses performed at lower (or other) levels of assembly, this dependence will be described.

For each analysis activity, the plan will include objectives, a description of the model, assumptions on which the models will be based, required output, criteria for assessing the acceptability of the results, the interaction with related test activity, if any, and requirements for reports. Analysis results will take into account tolerance build-ups in the parameters being used.

The plan should address GSE used in performance testing, as well as test data reduction (analysis, software and data product) electromagnetic interference (EMI)/electromagnetic compatibility (EMC) testing should also include turn on/off transients.

Any requirements verification being deferred to orbiter level of assembly should be justified.

The following documents as defined in Sections 9.2.2 to 9.7 may be included as part of the Spacecraft Performance Verification Plan or as separate documents to meet the Spacecraft Developer needs.

9.2.2 Environmental Verification Plan

An environmental verification plan will be prepared, as part of the system verification plan or as a separate document, that prescribes the tests and analyses that will collectively demonstrate that the hardware and software comply with the environmental verification requirements.

The environmental verification plan will provide the overall philosophy and approach to accomplishing the environmental verification program. For each test, it will include the level of assembly, the configuration of the item, objectives, test phases, and necessary functional operations.

It will also define a rationale for retest determination that does not invalidate previous verification activities. When appropriate, the interaction of the test and analysis activity will be described.

Limitations in the environmental verification program which preclude the verification by test of any system requirement will be documented. Alternative tests and analyses will be evaluated and implemented as appropriate, and an assessment of project risk will be included in the Spacecraft Performance Verification Plan.

9.2.3 System Performance Verification Matrix

A System Performance Verification Matrix will be prepared and maintained, to show each specification requirement, the reference source (to the specific paragraph or line item), the method of compliance, applicable procedure references, results, report reference numbers, etc. This matrix will be included in the system review data packages showing the current verification status as applicable. (Refer to Section 8 of this document).

9.2.4 Environmental Test Matrix

As an adjunct to the system/environmental verification plan, an environmental test matrix (ETM) will be prepared that summarizes all tests that will be performed on each component, each subsystem or instrument, and the payload. The purpose is to provide a ready reference to the contents of the test program in order to prevent the deletion of a portion thereof without an alternative means of accomplishing the objectives; All flight hardware, spares and prototypes (when appropriate) will be included in the matrix. The matrix will be prepared in conjunction with the initial environmental verification plan and will be updated as changes occur.

A complementary matrix will be kept showing the tests that have been performed on each component, subsystem, instrument, or payload (or other applicable level of assembly) including procured articles for flight. This will include tests performed on prototypes or engineering units used in the qualification program, and should indicate test results (pass/fail or malfunctions).

9.2.5 Environmental Verification Specification

As part of the Spacecraft Performance Verification Plan, or as a separate document, an environmental verification specification will be prepared that defines the specific environmental parameters that each hardware element is subjected to either by test or analysis in order to demonstrate its ability to meet the mission performance requirements. Such things as payload peculiarities and interaction with the launch vehicle will be taken into account.

9.2.6 Performance Verification Procedures

For each verification test activity conducted at the component, subsystem, and payload levels (or other appropriate levels) of assembly, a verification procedure will be prepared that describes the configuration of the test article, how each test activity contained in the verification plan and specification will be implemented.

Test procedures will contain details such as instrumentation monitoring, facility control sequences, test article functions, test parameters, pass/fail criteria, quality control checkpoints, data collection and reporting requirements. The procedures also will address safety and contamination control provisions.

9.2.7 Spacecraft Performance Verification Reports

After each component, subsystem, etc. verification activity has been completed, a report will be submitted. For each analysis activity, the report will describe the degree to which the objectives (in Section 9.2.1) were accomplished, how well the mathematical model was validated by related test data, and other such significant results. In addition, as-run verification procedures and all test and analysis data will be retained for review.

The Spacecraft Performance Verification Report will be developed and maintained “real-time” throughout the program summarizing the successful completion of verification activities, and showing that the applicable system performance specifications have been acceptably complied with prior to integration of hardware/software into the next higher level of assembly.

At the conclusion of the verification program, a final Spacecraft Performance Verification Report will be delivered comparing the hardware/software specifications with the final verified values (whether measured or computed).

9.3 ELECTRICAL FUNCTIONAL TEST REQUIREMENTS

The required electrical functional and performance tests specified in Section 9.2 of the Lunar Reconnaissance Orbiter Mission Assurance Requirements (431-RQMT-000174) (along with all other calibrations, functional/performance tests, measurements, demonstrations, alignments [and alignment verifications], end-to-end tests, simulations, etc. that are part of the overall verification program) will be described in the Spacecraft Developer ETM.

9.4 STRUCTURAL AND MECHANICAL REQUIREMENTS

The Spacecraft Developer will demonstrate compliance with the structural and mechanical requirements specified in Section 9.2 of the Lunar Reconnaissance Orbiter Mission Assurance Requirements (431-RQMT-000174) through a series of interdependent test and analysis activities. These demonstrations will verify design and specified factors of safety as well as ensure spacecraft interface compatibility, acceptable workmanship, and material integrity. The Spacecraft Developer will ensure through discussions/reviews with the LRO Safety Manager that, when it is appropriate, activities needed to satisfy the safety requirements are accomplished in conjunction with these demonstrations.

When planning the tests and analyses, the Spacecraft Developer will consider all expected environments including those of structural loads, vibroacoustics, mechanical shock, and pressure profiles. Mass properties and mechanical functioning shall also be verified.

9.5 ELECTROMAGNETIC COMPATIBILITY REQUIREMENTS

The electromagnetic characteristics of hardware will be designed in accordance with the requirements of Lunar Reconnaissance Orbiter Electrical System Specification (431-SPEC-000008) so that:

a. The Spacecraft and its elements do not generate EMI that could adversely affect its own subsystems and components, instruments, or the safety and operation of the launch vehicle or the launch site.

b. The Spacecraft and its subsystems and components are not susceptible to emissions that could adversely affect their safety and performance. This applies whether the emissions are self-generated or derived from other sources or whether they are intentional or unintentional.

9.6 VACUUM, THERMAL, AND HUMIDITY REQUIREMENTS

Using equipment and/or areas with controlled environments, the Spacecraft Developer will conduct a set of tests and analyses that collectively demonstrate the Spacecraft hardware's compliance with the vacuum, thermal, and humidity requirements defined in the Spacecraft Instrument-Spacecraft Interface Requirements Document and Sections 9.2 of the Lunar Reconnaissance Orbiter Mission Assurance Requirements (431-RQMT-000174), the General Environmental Verification Standards (GEVS) for Flight Programs and Projects (GSFC-STD-7000), Lunar Reconnaissance Orbiter Mechanical System Specification (431-SPEC-000012), Lunar Reconnaissance Orbiter Thermal System Specification (431-SPEC-000091), and the Lunar Reconnaissance Orbiter Orbiter Transportation, Handling, and Storage Specification (431-SPEC-**TBD**). The Spacecraft Developer program will demonstrate that:

a. The Spacecraft will perform satisfactorily in the vacuum and thermal environment of space

b. The Spacecraft's thermal design and the thermal control system will maintain the affected hardware within the established mission thermal limits

c. The Spacecraft hardware will withstand, as necessary, the temperature and humidity conditions of transportation, storage, and expendable launch vehicle (ELV) launch

9.7 SPACECRAFT/PAYLOAD VERIFICATION DOCUMENTATION

The documentation requirements of Section 9.2 also apply to the spacecraft/payload. Following integration of the instruments onto the spacecraft, the spacecraft System Verification Report will include the instrument information.

10.0 WORKMANSHIP AND ELECTRONIC PACKAGING

10.1 GENERAL

The Spacecraft Developer will plan and implement an Electronic Packaging and Processes Program to assure that all electronic packaging technologies, processes, and workmanship activities selected and applied meet mission objectives for quality and reliability.

10.2 WORKMANSHIP

The Spacecraft Developer shall use the following NASA and commercial workmanship standards:

a. NASA-STD-8739.3 – Soldered Electrical Connections

b. NASA-STD-8739.4 – Crimping, Interconnecting Cables, Harnesses, and Wiring

c. NASA-STD-8739.5 – Fiber Optic Terminations, Cable Assemblies, and Installation

d. ANSI/ESD S20.20 ESD Association Standard for the Development of an Electrostatic Discharge Control Program

e. NASA-STD-8739.1 – Workmanship Standard for Staking and Conformal Coating of Printed Wiring Boards and Assemblies

f. NASA-STD-8739.2 – Workmanship Standard for Surface Mount Technology

g. IPC-2221 – Generic Standard On Printed Board Design

h. IPC-2222 – Sectional Standard on Rigid PWB Design

i. IPC-2223 - Sectional Design Standard for Flexible Printed Boards

j. IPC-6011 – Generic Performance Specification for Printed Boards

k. IPC-6012 – Qualification and Performance Specification for Rigid Printed Boards supplemented with IPC-6012B Performance Specification Sheet for Space and Military Avionics

l. IPC-6013 – Qualification and Performance Specification for Flexible Printed Boards

m. IPC-6018 – Microwave End Product Board Inspection and Test

Alternate workmanship standards may be used when approved by the project. The Spacecraft Developer must submit, for review and approval, the alternate standard and the differences between the alternate standard and the required standard prior to project approval.

10.3 DESIGN

10.3.1 Printed Wiring Boards

Design of rigid printed wiring boards (PWBs) shall conform to the requirements of the IPC 6012B Class 3/A product per the IPC 6012B Performance Specification Sheet for Space and Military Avionics (PSSSMA). In the event of a conflict between the IPC design specifications, the 6012B Class 3 requirements, and the PSSSMA, the PSSSMA shall take precedence. Flexible PWBs and microwave boards shall conform to the requirements for Class 3 product as specified in IPC documents 6013 and 6018 referenced above.

10.3.2 Assemblies

The design considerations listed in the NASA workmanship and IPC standards listed above should be incorporated to the extent practical.

10.3.3 Ground Data Systems that Interface with Space Flight Hardware

GDS assemblies (this includes GSE) that interface directly with space flight hardware shall be designed and fabricated using space flight parts, materials and processes for any portion of the assemblies that mate with the flight hardware; or that will reside with the space flight hardware in environmental chambers or other test facilities that simulate a space flight environment (e.g., connectors, test cables, etc.). PWBs meeting these criteria shall be procured to IPC-6012B Class 3/A requirements (for rigid PWBs) or Class 3 requirements of the other IPC PWB specifications.

10.4 WORKMANSHIP REQUIREMENTS

10.4.1 Training and Certification

All personnel working on flight hardware shall be certified as having completed the required training, appropriate to their involvement, as defined in the above standards or, when approved by project management, in the developer's quality manual. This includes, but is not limited to, the aforementioned workmanship and electrostatic discharge (ESD) standards. At a minimum, certification shall include successful completion of formal training in the appropriate discipline. Re-certification shall be in accordance with the requirements defined in the above workmanship standards.

10.4.2 Flight and Harsh Environment Ground Systems Workmanship

10.4.2.1 Printed Wiring Boards

PWBs shall be manufactured in accordance with the Class 3 requirements in the above referenced IPC PWB manufacturing standards; rigid PWBs shall conform to IPC-6012B Class 3/A requirements as specified by the PSSSMA. The developer shall provide PWB test coupons to the GSFC Materials Engineering Branch (MEB) or a GSFC/MEB approved laboratory for evaluation, see CDRL 10.1. Coupon acceptance shall be obtained prior to population of flight PWBs. Test coupons and test reports are not required for delivery to GSFC/MEB if the developer has the test coupons evaluated by a laboratory that has been approved by the GSFC/MEB, however, they shall be retained and included as part of the Project's documentation/data deliverables package.

10.4.2.2 Assemblies

Assemblies shall be fabricated using the appropriate workmanship standards listed above (i.e., NASA-STD-8739.3 for hand soldering; NASA-STD-8739.4 for crimping/cabling; NASA-STD-8739.5 for fiber optic termination and installation; NASA-STD-8739.2 for Surface Mount Soldering, etc.) and ANSI/ESD S20.20.

10.4.3 Ground Systems (non-Flight) Workmanship

10.4.3.1 Printed Wiring Boards

PWBs not meeting the criteria of Section 10.3.3 shall be manufactured in accordance with the Class 3 requirements in the above referenced IPC PWB manufacturing standards.

10.4.3.2 Assemblies

Assemblies shall be fabricated using the Class 3 requirements of J-STD-001, IPC-A-610, and ANSI/ESD S20.20. If any conflicts between J-STD-001 and IPC-A-610 are encountered, the requirements in J-STD-001 shall take precedence.

10.4.4 Documentation

The developer shall document the procedures and processes that will be used to implement the above referenced workmanship, design, and ESD control standards; including any procedures or process requirements referenced in by those standards.

Alternate standards may be proposed by the developer. Proposals shall be accompanied by objective data documenting that mission safety or reliability will not be compromised. Their use is limited to the specific project and allowed only after they have been reviewed and approved by program management.

10.5 NEW/ADVANCED PACKAGING TECHNOLOGIES

New and/or advanced packaging technologies (e.g., Micro-Chip Modules [MCMs], stacked memories, chip on board) that have not previously been used in space flight applications must be reviewed and approved through the Parts Control Board (PCB) as defined in Section 12. When appropriate, a detailed Technology Validation Assessment Plan (TVAP) shall be developed for each new technology. A TVAP identifies the evaluations and data necessary for acceptance of the new/advanced technology for reliable use and conformance to project requirements.

New/advanced technologies may be part of the Parts Identification List (PIL) and Project Approved Parts List (PAPL) defined in Section 12 of this document.

11.0 MATERIALS, PROCESSES, AND LUBRICATION REQUIREMENTS

11.1 GENERAL REQUIREMENTS

Each developer shall implement a comprehensive Materials and Processes Control Plan (MPCP) (see CDRL 11-1) beginning at the design stage of the hardware. The MPCP will help ensure compliance with the MAR. The plan will ensure the success and safety of the mission by the appropriate selection, processing, inspection, and testing of the materials and lubricants employed to meet the operational requirements of the developer.

Proper selection and application of Materials and Processes (M&P) will help the project meet cost and schedule. For instance, selection of low outgassing materials and using qualified cleaning procedures for hardware will probably reduce hardware back-out times from weeks to days. Testing and evaluation of materials for non-heritage applications prior to build will eliminate potential problems during the I&T phase.

Materials, processes and lubrication approval by the LRO Materials Assurance Engineer (MAE) are required for each usage or application in space-flight hardware.

11.2 MATERIALS SELECTION REQUIREMENTS

To qualify as a material compliant with intended spaceflight use, a material must have a satisfactory flight heritage, be approved by the MAE and meet the following applicable selection criteria;

1. Stress corrosion cracking for structural applications
2. Vacuum outgassing
3. Lubrication systems that meets design limits
4. Fasteners integrity for structural applications
5. PWB integrity (see Section 10, Workmanship and Electronic Packaging)
6. Process selection
7. Procurement

The selection and use of material with hazardous properties (such as flammability and toxicity) shall meet the requirements specified in AFSPCM 91-710, “Range Safety User Requirements Manual,” Chapters 10 and 12.

A material that has limited spaceflight heritage or does not meet the applicable selection requirements listed above shall be considered non-compliant. In that case, if there are no alternatives available to select a compliant material, the material’s usage will be justified and approved prior to use for the desired application on the basis of test, similarity, analyses, inspection, existing data, or a combination of those data. Material use in structural applications shall be highly resistant to stress corrosion cracking (SCC) as specified in MSFC-STD-3029. A Materials Usage Agreement (MUA) and/or a Stress Corrosion Evaluation Form shall be submitted to the MAE for approval for use of the proposed non-compliant material. Both forms will be required for a material that does not meet the SCC requirements.

In order to minimize materials and lubricant problems during use in space hardware, the developer shall anticipate and consider potential application problem areas. Potential problem areas and application factors to be considered include radiation effects, thermal cycling, stress corrosion cracking, galvanic corrosion, hydrogen embrittlement, lubrication, contamination of cooled surfaces, composite materials, atomic oxygen, limited life, vacuum outgassing, toxicity, flammability and fracture toughness, as well as the properties required by each material usage or application.

11.2.1 Stress Corrosion Cracking of Inorganic Materials

Materials used in structural applications shall be highly resistant to SCC (i.e., MSFC-STD-3029, TABLE I-A through TABLE I-E). MUAs shall be required for those with moderate resistance to SCC (MSFC-STD-3029, TABLE II-A through TABLE II-C), or low resistance to SCC (MSFC-STD-3029, TABLE III-A through TABLE III-D), or those not listed in MSFC-STD-3029. This requirement is not applicable to materials used in non-structural applications, such as EEE parts or electronic modules.

The developer shall prepared and submit an Inorganic Materials and Composites Usage. The list shall be submitted to the MAE for review and approval.

The use of pure tin, zinc, and cadmium plating is prohibited in any flight application and requires an MUA prior to use of the material. Bright tin, cadmium, and zinc plating will develop whisker growth. For tin, these have been measured up to 12.5 micron in diameter and up to 10 millimeters (mm_ in length. These whiskers can result in short circuits, plasma arcing and debris generation within the spacecraft. Zinc and cadmium plating also evaporate in vacuum environments and may deposit on optics or electronics, posing potential risks to flight hardware.

11.2.2 Vacuum Outgassing of Polymeric Materials

All polymeric materials shall meet the general outgassing requirements of 1% maximum Total Mass Loss (TML) and 0.1 % maximum Collected Volatile Condensable Materials (CVCM) when tested per ASTM E595. If the material exceeds these maximum limits the developer shall be required to bring it into compliance via a bakeout, replace it with a different material, or submit a MUA for its application. In the latter case, the MUA shall be reviewed against the LRO requirements and dispositioned by the MAE.

(Note that the overall mission contamination control requirements may demand a more stringent outgassing criteria.)

The developer shall prepare and submit a Polymeric Materials and Composites Usage. The list shall be submitted to the MAE for review and approval.

11.2.3 Lubrication Systems

Moving mechanisms are required to have a lubrication system, preferably of a heritage design, that will survive the life-time operation of the instrument or spacecraft. A life test shall be performed for non-heritage designs and the data available at all reviews. The lubricant's labyrinth seal design shall be such that the lubricant's outgassing shall not affect the operation of the instrument and those in the vicinity or the spacecraft. The designer shall provide a lubrication loss analysis to show that this system will meet the designed life-time requirement. This analysis shall be submitted to the MAE and shall be reviewed by a Tribologist in the Materials Engineering Branch (MEB).

The developer will prepare and document a Lubrication Usage List. The list shall be submitted to the MAE for review and approval.

11.2.4 Process Selection Requirements

The developer shall select a process that is appropriate for the materials involved in the intended application. Metallic materials that are used in structural applications shall be processed (heat treated, annealed, etc.) in such a way to minimize the stresses incurred from the manufacturing, machining, and/or assembly. Processes for cleaning and handling flight hardware shall be established before hardware assembly begins. Adhesive joining of structural, non-structural, or optical components shall be either of a heritage design or pre-qualified via testing before finalizing the design. Thermal control materials and coatings shall be carefully selected to meet LRO requirements. Appropriate handling procedures shall be generated to prevent damage of fragile coatings or optical surfaces during assembly and transport.

The developer will prepare and document a Material Processes Utilization. The list shall be submitted to MAE for review and approval.

11.2.5 Fasteners

The developer will comply with the procurement documentation and test requirements for flight hardware and critical GSE fasteners contained in 541-PG-8072.1.2, GSFC Fastener Integrity Requirements. To document this process, the developer shall prepare a Fastener Control Plan for submission to the MAE.

Additionally, it is recommended (that upon request) that material test reports for fastener lots be submitted to the MAE for information. Fasteners made of plain carbon or low alloy steel must be protected from corrosion. When plating is specified, it must be compatible with the space environment. On steels harder than RC 33, plating will be applied by a process that is not embrittling to the steel.

11.2.6 Materials Used in "Off-the-Shelf Hardware"

"Off-the-shelf hardware" for which a detailed materials list is not available and where the included materials cannot be easily identified and/or changed will be treated as non-compliant.

The developer shall submit a MUA that defines the appropriate measures that will be used to ensure that all materials in the "off the shelf" hardware will be acceptable for use. Such measures might include any one or a combination of the following: replace unknown or non-compliant materials within the hardware with compliant materials, or hermetically seal, or vacuum bake out the questionable hardware to bring the hardware into a suitable condition for use. When a vacuum bake-out is the selected method, it must incorporate a quartz crystal microbalance (QCM) and cold finger to enable a determination of the duration and effectiveness of the bake-out as well as compliance with the spacecraft contamination plan and error budget.

11.3 MATERIALS PROCUREMENT REQUIREMENTS

11.3.1 Purchased Raw Materials

Raw materials purchased by the developer must be accompanied by the results of nondestructive, chemical and physical tests, or a Certificate of Compliance. This information shall be available to the LRO Office for review upon request.

If a metallic material is obtained from another source or project without this information, the developer shall provide the MEB a test sample for evaluation to determine composition and treatment.

11.3.2 Raw Materials Used in Purchased Products

The developer will require that their suppliers meet the requirements of Section 11.3.1 of this document and provide, upon request, the results of acceptance tests and analyses performed on raw materials.

11.3.3 Purchase of Fasteners

Procurement of fasteners shall meet the 541-PG-8072.1.2 requirements. GSFC Store Stock has a limited inventory of metric and English fasteners for flight application. These fasteners can be purchased via http://logsweb.gsfc.nasa.gov or by contacting the Logistics Management Division, Code 230.

11.4 SHELF-LIFE CONTROL REQUIREMENT FOR POLYMERIC MATERIALS

Polymeric materials that have a limited shelf-life may be controlled by a process that identifies the start date (manufacturer's processing, shipment date, or date of receipt, etc.), the storage conditions associated with a specified shelf-life, and expiration date. Materials such as o-rings, rubber seals, solder flux, tape, uncured polymers, lubricated bearings and paints will be included. The use of materials whose date code has expired requires that the developer demonstrate, by means of appropriate tests, that the properties of the materials have not been compromised for their intended use. Such materials may be approved by the LRO by means of a waiver. When a limited-life piece part is installed in a subassembly, its usage must be approved by the MAE. This may be accomplished by including the subassembly item in the Limited-Life List.

11.5 IMPLEMENTATION

Open communication between the developer, SAM, MAE and Project personnel is highly recommended towards implementing these M&P requirements. It is advised that the project fully utilize the range of services that the MEB has to offer to the project.

The developer and Project personnel shall inform the MAE via the SAM of any potentially non-compliant M&P being used in the spacecraft and instruments prior to build. They shall provide the SAM the following documentation:

a. M&P and Lubrication List 30 days before PDR and CDR. It shall include lists for subsystems and top level assemblies.

b. MUAs for non-compliant materials after CDR, if applicable

c. PWB Coupons Test Request for incoming bare boards (Appendix D)

d. Fastener Integrity Plan: it should include a list of fasteners used in single-point failure applications, those of size #10 and larger used in fail-safe applications, and the testing being planned to comply with the 541-PG-8072.1.2 requirements.

The MAE:

a. The MPCB will be implemented by the MAE to resolve materials and procurements problems and discrepancies.

b. Shall review and relay to the Systems Lead Engineers and Procurement Activity any potential M&P-related problems from Government Industry Data Exchange Program (GIDEP) Alerts system and from other flight projects.

c. Shall assist the Systems Engineering Team with materials selection, which includes any applicable testing prior to build or after instrument-level or spacecraft-level testing.

d. Shall inform the developer Contamination Control Engineer of any polymeric material that is not compliant with the outgassing requirements at the final build and work with him/her to minimize its outgassing effect on the spacecraft and instruments.

(For a complete listing of MAE support activities, review 541-PG-7120.2.1.)

11.6 REFERENCES

The System Engineering Team can use the following resources as a reference during the design stage. However, team members are encouraged to consult with the MAE via the SAM for any M&P-related support.

a. Lunar Reconnaissance Orbiter Mission Assurance Requirements, 431-RQMT-000174

b. Outgassing: GSFC database http://outgassing.nasa.gov or telnet the MAPTIS data base maptis.msfc.nasa.gov

c. SCC: MSFC-STD-3029 via http:// standards.nasa.gov

d. Materials tips: a limited number of tips are currently available on line. Please check with the MAE for the remainder.

e. Materials Processing Documents: They include procedures for conformal coating and staking, adhesives bonding of temperature sensing devise and thermo foil heaters, electromagnetic radio frequency interference (EMRI)/RF interference (RFI) shielding of connectors, torque striping of fasteners, various nondestructive evaluation (NDE) procedures for etching and dye penetrant inspection of fracture critical hardware and many others.

11.7 CONTACTS

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12.0 EEE PARTS REQUIREMENTS

12.1 GENERAL

The Spacecraft Developer will plan and implement an EEE Parts Control Program to assure that all parts selected for use in flight hardware meet mission objectives for quality and reliability. This plan establishes the minimal requirements of the LRO Program standard parts baseline and is based on requirements specified in GSFC-EEE-INST-002, “Instructions for EEE Parts Selection, Screening, Qualification, and Derating”, Level 2.

The minimum acceptable EEE part grade for EEE parts for this program is level 2 with 100% Particle Impact Noise Detection (PIND) screening for cavity bodied devices. This assumes that the radiation hardness requirements and system reliability goals are also being met.

The Spacecraft Developer will prepare a Parts Control Plan (PCP) (Refer to CDRL, DID 12.1) describing the approach and methodology for implementing the Parts Control Program. The PCP will also define the Spacecraft Developer’s criteria for parts selection and approval based on the guidelines of this section.

12.2 ELECTRICAL, ELECTRONIC, AND ELECTROMECHANICAL PARTS

All part commodities identified in the NASA Parts Selection List (NPSL) http://nepp.nasa.gov are considered EEE parts and will be subjected to the requirements set forth in this section. Custom or advanced technology devices such as custom hybrid microcircuits, detectors, Application Specific Integrated Circuits (ASIC), MCM, and magnetics will also be subject to parts control appropriate for the individual technology.

12.3 PARTS CONTROL BOARD

The Spacecraft Developer will establish a PCB to facilitate the management, selection, standardization, and control of parts and associated documentation for the duration of the project. The PCB will be responsible for the review and approval of all parts for conformance to established criteria, and for developing a PIL and maintaining a PAPL. In addition, the PCB will be responsible for all parts activities such as failure investigations, disposition of non-conformances, and problem resolutions. PCB operating procedures will be included as part of the PCP. The PCB shall include the LRO Project EEE Parts Engineer as a technical consultant and for part approval. PCB meetings will be held when needed. LRO parts engineer participation at PCB meetings is required.

12.3.1 PCB Meetings

PCB meetings will be convened as necessary to evaluate acceptance of EEE parts and/or materials in a timely manner to support the Spacecraft Developer Project schedule. Meetings will be held prior to the procurement of parts and/or materials. At a minimum, the PCB meetings will be convened prior to the PDR to determine the acceptability of EEE parts including those proposed for use by the Spacecraft Developer and/or subcontractors, vendors, or collaborators.

Emergency PCB meetings will be convened at the discretion of the PCB chair via telecon or e-mail to meet Project needs and schedules.

The chair will be responsible for the scheduling of PCB meetings and will notify all members, including the LRO Project Office and the Project EEE Parts Engineer, at least 10 working days prior to each (non-emergency) meeting via telephone or e-mail.

The LRO Project Office may participate in PCB meetings and will be notified in advance of all upcoming meetings. Meeting minutes or records will be maintained by Spacecraft Developer to document all decisions made and a copy provided to the LRO Project Office within three days of convening the meeting. (Refer to the CDRL, DID 12-2.) The LRO Project Office may elect to overturn decisions involving non-conformances within ten days after receipt of meeting minutes.

12.4 PARTS SELECTION AND PROCESSING

All EEE parts will be selected and processed in accordance with GSFC-EEE-INST-002, Instructions for EEE Parts Selection, Screening, Qualification, and Derating. The Part Quality Level 2 defined in GSFC-EEE-INST-002 will apply to this program.

Parts selected from the NASA Parts Selection List (NPSL) http://nepp.nasa.gov are considered Qualified. However, they shall be evaluated for compliance to the radiation and reliability requirement of the Program and must be evaluated by the PCB.

12.4.1 Parts Selection Criteria

Parts for use on the program shall be selected in order of preference as listed in this section. Parts falling into the categories for paragraphs numbered A through I shall be evaluated by the PCB for compliance to the screening requirements of GSFC-EEE-INST-002 and need not be subjected to any additional qualification or Quality Conformance Inspection (QCI) tests. Parts falling into the categories for paragraphs numbered J through L may require additional testing to be in conformance with the requirements of GSFC-EEE-INST-002. All parts must be evaluated for radiation hardness characteristics (Total Ionizing Dose [TID], Single-Event Upset [SEU], and Single-Event Latch-up [SEL]) as per the program requirement. PIND testing shall be performed on all cavity devices.

a. Parts listed in the NPSL. Parts with flight heritage history shall be reviewed for compliance with GSFC-EEE-INST-002 Level 2 prior to use. Parts will be procured in accordance with the appropriate specification designated for that part.

b. MIL-M-38510, Class B or better microcircuits procured from a Qualified Products List (QPL) supplier. MIL-M-38510, class B microcircuits do not require lot specific 1000-hour-life test. http://www.dscc.dla.mil/offices/sourcing_and_qualification and http://www.dscc.dla.mil/offices/doc_control.

c. MIL-PRF-38535, Class Q or better microcircuits procured to Standard Military Drawings (SMDs) from a supplier listed in the Qualified Manufacturer List (QML) at http://www.dscc.dla.mil/offices/sourcing_and_qualification and http://www.dscc.dla.mil/offices/doc_control.

d. MIL-PRF-38534, Class H or better hybrid microcircuits procured from a supplier listed in the QML.

e. Microcircuits compliant with Paragraph 1.2.1 of MIL-STD-883 and procured from manufacturers having QPL or QML status for parts of the same technology. Parts procured from manufacturers without QPL or QML status shall be procured with precap visual or Destructive Physical Analysis (DPA) in addition to lot-specific or generic Group C QCI data that is within one (1) year of the lot date code of the parts being procured. If Group C testing is not available, 1000 hours of life testing on 22 samples will be performed.

f. Manufacturer's in-house reliability-processed parts provided all screening tests listed in GSFC-EEE-INST-002 for a Quality Level 2 part has been satisfied. The high-reliability process flow shall be formally documented by the manufacturer in cases in which changes would require a revision to the flow documentation. Tests not included in the manufacturer's reliability flow must be performed at an independent test facility or at GSFC. Parts shall be procured following this guideline with lot-specific or generic Group C QCI data and shall be approved by the PCB.

g. MIL-PRF-19500, JANTX, JANTXV, and JANS semiconductors procured from a QPL-listed supplier and screened per GSFC-EEE-INST-002. The DPA requirements on JANTXV level parts will be evaluated by the PCB on a case-by-case basis. A DPA on JANTX level devices shall be performed.

h. Established Reliability (EREL) passive components procured from a QPL-listed supplier for the appropriate military specification. Part failure rates should be in accordance to the guidelines in GSFC-EEE-INST-002 for Quality Level 2 parts.

i. Parts previously approved by GSFC on previous flight missions for a system similar to the one being procured will be evaluated by the PCB for continued compliance to the project requirements. This will be accomplished by determining that:

   1) No changes have been made to the previously approved, Source Control Drawing (SCD), vendor list, or processes.

   2) The previous project's parts quality level is identical to the LRO Project.

   3) Parts have undergone effective screening.

j. Any parts not meeting the criteria specified in paragraphs numbered A through I of this section shall be screened in accordance with the screening requirement specified in GSFC-EEE-INST-002, Quality Level 2 for each commodity. Changes in form, fit, function, reliability, or manufacturer shall be cause to require improving the screening to meet the screening requirement of GSFC-EEE-INST-002, Quality Level 2, for each appropriate commodity.

k. Plastic Encapsulated Microcircuits (PEMs) and commercial parts should be the exception rather than the rule. If a part is available in a hermetic package and plastic package, the hermetic package will be used. The PCB will approve all PEMs. Screening and Qualification requirements shall be in accordance with GSFC-EEE-INST-002.

l. Pre-cap inspection at subcontractor, vendor, or collaborator’s facilities will be performed as required on hybrid microcircuits (Direct Current [DC]/DC converters) and other complex microcircuits, such as ASICs, MCM, and 3-D stacks as approved by the PCB. If pre-cap inspection is not performed during screening, DPA will be performed.

GSFC-EEE-INST-002 shall be used as a reference document while preparing Part Specifications and SCDs when required.

12.4.2 <u>Custom Devices</u>

In addition to applicable requirements of 311-INST-002, custom microcircuits, hybrid microcircuits, MCM, ASIC, magnetics, etc. planned for use by the Spacecraft Developer will be subjected to a design review.

The review may be conducted as part of the PCB activity. The design review will address, at a minimum, derating of elements, method used to assure each element reliability, assembly process and materials, and method for assuring adequate thermal matching of materials.

12.4.2.1 Magnetics

Magnetic devices (e.g., transformers and inductors) shall be assembled and screened to requirements of MIL-STD-981 and MIL-PRF-27 wherever possible or as per source control documents.

12.4.2.2 Capacitors

50-volt (V) ceramic capacitors used in applications < 10V DC will require steady state humidity low-voltage testing on 12 samples in accordance with MIL-PRF-123. Tantalum Capacitors shall require 100 percent surge current testing in accordance with MIL-PRF-39003/10 for leaded capacitors or MIL-PRF-55365/4 for chip capacitors. NPSL application notes shall be followed.

12.4.2.3 Relays

Relays not subjected to small pore cleaning and internal visual inspection shall require DPA. No relays with pure tin enclosures, headers, or terminal pins will be used.

12.4.3 Derating

All EEE parts will be used in accordance with the derating guidelines of the GSFC-EEE-INST-002. The Spacecraft Developer will maintain documentation on parts derating analysis and will make it available for LRO Project Office review.

12.4.4 Parts Stress Analysis

Each application of EEE parts will be subjected to stress analyses for conformance with the applicable derating guidelines as specified in EEE-INST-001. The analyses will be performed at the most stressful values that result from specified performance and environmental requirements (e.g., temperature and voltage) on the assembly or component. The analyses will be performed in close coordination with the packaging reviews and thermal analyses and they will be required input data for component-level design reviews. The analyses with summary sheets and updates will be maintained at the developer's facility for the Government to review/audit. (Refer to the CDRL, DID 12-3.) The results of the analyses will be presented at all design reviews starting with a preliminary report at the PDR. The presentations will include comments on how the analysis was used to perform design trade-offs or how the results were taken into consideration when making design or risk management decisions.

12.4.5 Radiation Hardness

All parts will be selected to meet their intended application in the predicted mission radiation environment. The radiation environment consists of two separate effects, those of total ionizing dose and single-event effects. The Spacecraft Developer will document the analysis for each part with respect to both effects.

12.4.6 Verification Testing

Verification of screening or qualification tests by re-testing is not required unless deemed necessary as indicated by failure history, GIDEP Alerts, or other reliability concerns. If required, testing will be in accordance with GSFC-EEE-INST-002 as determined by the PCB. The Spacecraft Developer, however, will be responsible for the performance of supplier audits, surveys, source inspections, witnessing of tests, and/or data review to verify conformance to established requirements.

12.4.7 Destructive Physical Analysis

A sample of each lot date code of microcircuits, hybrid microcircuits, and semiconductor devices will be subjected to a DPA as decided by the PCB. All other parts may require a sample DPA if it is deemed necessary as indicated by failure history, GIDEP Alerts, or other reliability concerns. DPA tests, procedures, sample size and criteria will be as specified in GSFC specification S-311-M-70, Destructive Physical Analysis. The Spacecraft Developer's procedures for DPA may be used in place of S-311-M-70 (with approval of the LRO Project EEE Parts Engineer) and will be submitted with the PCP. Variation to the DPA sample size requirements, due to part complexity, availability or cost, will be determined and approved by the PCB on a case-by-case basis. In lieu of performing the required DPA's, the Spacecraft Developer may provide the required number of DPA samples to the LRO Project Office for DPA. This will be accomplished on a case by case basis through mutual agreement by the Spacecraft Developer and the LRO Project Office.

12.4.8 Failure Analysis

Failure analyses, performed by experienced personnel, will be required to support the non conformance reporting system. The (in-house or out-of-house) failure analysis laboratory shall be equipped to analyze parts to the extent necessary to ensure an understanding of the failure mode and cause. The failure analyses shall be available to the LRO Project Office for review.

12.4.9 Parts Age Control

Parts drawn from controlled storage after 5 years from the date of the last full screen must be subjected to a full 100 percent re-screen and sample DPA as decided by the PCB. Alternative test plans may be used as determined and approved by the PCB on a case-by case basis. Parts over 10 years from the date of the last full screen or stored in other than controlled conditions where they are exposed to the elements or sources of contamination shall not be used.

12.5 PARTS LISTS

The Spacecraft Developer will create and maintain a PIL which becomes the PAPL after approval by the PCB for the duration of the project. All parts must be approved before initiation of flight procurement activity. The PAPL will be converted to an as-build part list (ABPL) and will be submitted to GSFC as a final ABPL. (Refer to the CDRL, DID 12-4)

12.5.1 Parts Traceability Control

Traceability records for all parts from incoming inspection through board installation will be maintained. Parts replacement control traceability shall also be tracked for all parts replaced. Records of all flight parts, including all part failures from the unit level acceptance testing and all destructive test samples, shall be kept on file for the life of the program and part lists shall be updated.

12.6 PARTS REUSE

EEE parts, which have been installed in an assembly, and removed for any reason, shall not be used again in flight hardware, unless removal, retest, and reinstallation procedures have been approved by the PCB.

12.7 ALERTS

The Spacecraft Developer PCB will be responsible for the review and disposition of GIDEP Alerts for applicability to the parts proposed for use or incorporated into the design. In addition, any NASA Alerts and Advisories provided to the Spacecraft Developer by GSFC will be reviewed and dispositioned. Alert applicability, impact, and corrective actions will be documented and reported to the LRO Project Office with the monthly management or quality assurance report. Additionally, when appropriate, the Spacecraft Developer will prepare, or assist GSFC personnel in preparing Alerts. (CDRL, DID 12-5) A GIDEP/ALERT matrix will be developed and maintained by the Spacecraft Developer (Lunar Reconnaissance Orbiter Mission Assurance Requirements (431-RQMT-000174, Section 15) (CDRL 12-6).

13.0 CONTAMINATION CONTROL REQUIREMENTS

13.1 GENERAL

The Spacecraft Developer will plan and implement a contamination control program applicable to the hardware. The program will establish the specific cleanliness requirements and delineate the approaches in a Contamination Control Plan (CCP). (Refer to the CDRL 13-1)

13.2 CONTAMINATION CONTROL PLAN

The Spacecraft Developer will prepare a CCP that describes the procedures and controls that will be followed to control contamination. The CCP will define a contamination allowance for performance degradation of contamination sensitive hardware such that, even in the degraded state, the hardware will meet its mission objectives. The CCP will establish the implementation and describe the methods that will be used to measure and maintain the levels of cleanliness required during each of the various phases of the hardware's lifetime. In general, all mission hardware should be compatible with the most contamination-sensitive components.

Performance Assurance Personnel will monitor the fabrication, assembly and testing activities for compliance with the CCP. Out of tolerance conditions will result in a request for corrective action to responsible personnel and be processed per the developer's nonconformance corrective action reporting system as outlined in their quality manual.

13.3 MATERIALS OUTGASSING

All materials shall be screened in accordance with NASA Reference Publication 1124, Outgassing Data for Selecting Spacecraft Materials. Individual material outgassing data will be established based on hardware's operating conditions and reviewed by GSFC.

13.4 THERMAL VACUUM BAKEOUT

The Spacecraft Developer will determine the need to perform thermal vacuum bakeouts of flight hardware. If performed, the parameters of such bakeouts (e.g., temperature, duration, and pressure) must be individualized depending on materials used, the fabrication environment, and the established contamination allowance.

13.5 HARDWARE HANDLING

The Spacecraft Developer will practice clean room standards in handling hardware. The contamination potential of material and equipment used in cleaning, handling, packaging, tent enclosures, shipping containers, bagging (e.g., anti-static film materials), and purging will be addressed.

13.6 MATERIALS PRECAUTIONS

Aerospace experience has demonstrated the need for an advisory on the procurement and use of Kapton tapes in ESD controlled areas. Unless specified on procurements and tested for conformance, Kapton tape adhesive can be manufactured with either acrylic or silicone in nature. The silicone adhesive has proven to contaminate sensitive spaceflight hardware and therefore must not be used on any aerospace system. Only acrylic adhesive is approved for spaceflight hardware.

14.0 ELECTROSTATIC DISCHARGE CONTROL

14.1 GENERAL

The Spacecraft Developer will establish and maintain an ESD program that complies with ANSI/ESD S20.20, ESD Association Standard for the Development of an Electrostatic Discharge Control Program for protection of electrical and electronic parts, assemblies, and equipment (excluding electrically initiated explosive devices).

Documentation of compliance with ESD controls during electronic hardware fabrication (including daily recording of wrist strap usage) will be maintained and audited by QA. Continuous ESD monitoring devices are preferred while handling flight electronics.

Special ESD program requirements shall be defined and controls shall be implemented in accordance with the sensitivity of EEE parts and electronic packaging as applicable.

15.0 END ITEM DATA PACKAGE

The developer will prepare an End Item Data Package (EIDP) that consists of the following documentation, which will be submitted at the Spacecraft PSR. Documentation is to address both hardware and software.

- Acceptance testing (as run) procedures and reports including total number of failure free testing
- Environmental Testing (as run) reports
- Final Assembly Work Order
- Material Certification or Analysis Forms
- Waivers, Deviations or Material Usage Agreements
- As-Built EEE Parts List
- As-Built Materials List (ABML)
- End Item Inspection report
- Nonconformance or problem/failure reports and corrective action summaries
- List of Open items or one time occurrences
- As built final assembly drawing
- Any pertinent analyses (mechanical, electrical, reliability, stress, thermal, worst case)
- As-Built Configuration List (Item, Manufacturer, Model, etc)
- Certificate of Compliance signed by management
- Requirements Verification Matrix

Appendix A. Contract Deliverable Requirements List and Data Item Description

CDRL Number	Name of Document	Delivery to GSFC
1-1	Heritage Hardware Matrix or Report	30 days prior to PDR. Updates as Developed. Final due to GSFC 45 days prior to CDR.
2-1	Quality Manual	60 days after contract award
2-2	Problem Failure Reports (PFRs)	Within 24 hours of occurrence
2-3	Subcontractor Assurance Verification Matrix	Initial maintained throughout system fabrication. Final due 30 days prior to PSR
3-1	System Safety Program Plan	45 days after contract award
3-2	Safety Requirements Compliance Checklist	Due with submission of safety assessment report (SAR)
3-3	Preliminary Hazard Analysis (PHA)	30 days prior to PDR
3-4	Operations Hazard Analysis	45 days prior to shipping to GSFC or 15 days prior to ant I&T operations
3-5	Safety Assessment Report (SAR)	Preliminary at PDR. Update at CDR. Final 60 days before PSR
3-6	Missile System Prelaunch Safety Package (MSPSP)	Preliminary at PDR. Update at CDR. Final 60 days before PSR
3-7	Hazard Control Verification and Tracking	Initial draft at CDR with final due at Spacecraft PSR Updates as requested by GSFC Project Safety Manager (PSM)
3-7	Safety Noncompliance Requests	As generated
3-8	Ground Operations Procedures	60 days prior to PSR
3-9	Safety Variances	As identified by Project PSM
3-10	Orbital Debris Assessment	Preliminary assessment prior PDR, updated package 45 days prior to CDR and a final package at PER
3-11	Operations Hazard Analysis for I&T activities in the GSFC 7/10/15/29 Complex	Preliminary OHA 60 day prior to shipping to GSFC. A final version must be submitted 15 days prior to shipping and must be approved by Code 302 prior to initiating any I&T activities.
4-1	Reliability Program Plan (RPP)	Draft 30 days after contract award for GSFC review. Final 30 days before developer PDR for GSFC review and approval. Updates as required including changes for GSFC review and approval
4-2	Probabilistic Risk Assessment (PRA)	Preliminary PRA 30 days before PDR for review. Final PRA 30 days after CDR for approval. Updates as changes are made; between CDR and delivery, for approval.
4-3	Failure Mode and Effects Analysis (FMEA) and Critical Items List (CIL)	Preliminary 30 days before PDR for GSFC review. Final 30 days before CDR for GSFC review. Updates as required including changes for GSFC review.
4-4	Fault Tree Analysis (FTA)	Preliminary 30 days before PDR for GSFC review. Final 30 days before CDR for GSFC review. Updates as required including changes for GSFC review

CDRL Number	Name of Document	Delivery to GSFC
4-5	Parts Stress Analysis	Final 45 days before GSFC CDR for GSFC review Updates to include changes as required for GSFC review
4-6	Worst Case Analysis	Available 30 days prior to component CDR Updates with design changes.
4-7	Reliability Assessments and Predictions	Preliminary 30 days before PDR for GSFC review. Final 30 days before CDR for GSFC review. Updates as required including changes for GSFC review.
4-8	Trend Analysis	List of parameters to be monitored at time of CDR for information. Trend Analysis Reports at time of PER and FRR for information
4-9	Limited-Life Items List	Preliminary 30 days before PDR for review. Final 30 days before CDR for approval. Updates as changes are made; between CDR and delivery, for approval
5-1	Software Assurance Plan	Initial draft due 90 days after contract award. Final due no later than requirements phase. Updated periodically throughout the lifecycle, if necessary.
5-2	Software Management Plan	Initial draft due 90 days after contract award. Final due no later than requirements phase. Updated periodically throughout the lifecycle, if necessary.
5-3	Software Configuration Management Plan	Initial draft due 90 days after contract award. Final due no later than requirements phase. Updated periodically throughout the lifecycle, if necessary.
5-4	Software Reliability Plan	Initial draft due 90 days after contract award. Final due no later than requirements phase. Updated periodically throughout the lifecycle, if necessary.
5-5	Software Requirements Specification	Initial draft due upon customer/supplier agreement on software functionality. Final due no later than the CDR. Updated periodically throughout the lifecycle, as necessitated by requirement changes.
7-1	Risk Management Plan	Preliminary 30 days before PDR for GSFC review. Final 30 days before CDR for GSFC review. Updates as required including changes for GSFC review.
9-1	System Performance Verification Plan	Preliminary at PDR for GSFC review. Final at CDR for GSFC approval. Updates as required.
9-2	Performance Verification Procedure	30 days prior to test for GSFC approval.
9-3	Verification Reports	Preliminary report 72 hours after test for GSFC information. Final report 30 days after verification activity for GSFC information System Performance Verification Report: Preliminary at CDR. Final report 30 days following on-orbit check out.

CDRL Number	Name of Document	Delivery to GSFC
10-1	Printed Wiring Board (PWB) Test Coupons	Prior to population of flight PWBs. Applies individually to each procured lot of boards.
11-1	Materials and Processes Control Program Plan.	The MPCP shall be developed and delivered as part of the proposal for GSFC review. Final is due 90 days after contract award.
11-2	As-Designed Materials and Processes List (ADMPL)	The ADMPL shall be submitted to the LRO 30 days prior to the PDR.
11-3	Materials Usage Agreement (MUA)	Provide to the MAE, with the polymeric and composite materials usage list, flammable materials usage list, odor and toxic offgassing materials usage list or the inorganic materials usage list for approval.
11-4	Stress Corrosion Evaluation Form	Provide to LRO MAE for review. Initial at PDR final due 45 days prior to CDR.
11-5	Polymeric Materials and Composites Usage List	Provide to the LRO Project Office 30 days before developer PDR for review, 30 days before developer CDR for approval and 30 days before acceptance for approval.
11-6	Materials Waiver	Provide to the LRO Project Office for approval 30 days prior to the CDR or use
11-7	Inorganic Materials List	Initial 30 days before PDR for review Update 30 days before CDR for Approval Final 30 days before acceptance for approval
11-8	Fastener Control Plan	30 days before PDR
11-9	Lubrication Usage List	Initial 30 days before PDR for review Update 30 days before CDR for Approval Final 30 days before acceptance for approval
11-10	Life Test Plan for Lubricated Mechanisms	Initial 30 days before PDR for review Update 30 days before CDR for Approval Final 30 days before acceptance for approval
11-11	Materials Process List	Initial 30 days before PDR for review Update 30 days before CDR for Approval Final 30 days before acceptance for approval
11-12	Materials Certification	Maintain with assembly cert log/WOA
12-1	EEE Parts Control Plan	PDR for review CDR for approval
12-2	Parts Control Board Reports	Due to Project Within 5 days of meeting
12-3	Parts Identification List (PIL)	30 days before PDR for review Updated 30 days before CDR for Approval As built 60 days before delivery of the end item
12-4	Alert Advisory Report	Respond within 25 days of alert notice Maintain throughout project life cycle
13-1	Contamination Control Plan (CCP)	30 days before PDR for review 30 days before CDR for Approval
14-1	ESD Control Plan	30 days before PDR for review 30 days before CDR for approval

CDRL Number	Name of Document	Delivery to GSFC
15-1	End Item Data Package (EIDP)	Subsystem with end item delivery Orbiter-30 days prior to PSR

Appendix B. Abbreviations and Acronyms

Abbreviation/ Acronym	DEFINITION
ABPL	As-Built Parts List
ADMPL	As-Designed Materials and Processes List
AFSCM	Air Force
ANSI	
ASTM	
AR	Acceptance Review
ASIC	Application Specific Integrated Circuits
ASQC	
CCB	Configuration Control Board
CCP	Contamination Control Plan
CCR	Configuration Change Request
CDR	Critical Design Review
CDRL	Contract Delivery Requirements List
CIL	Critical Items List
CM	Configuration Management
CMO	Configuration Management Office
CVCM	Collected Volatile Condensable Mass
DC	Direct Current
DID	Data Item Description
DPA	Destructive Physical Analysis
EEE	Electrical, Electronic, and Electromechanical
EIDP	End Item Data Package
ELV	Expendable Launch Vehicle
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMRI	Electromagnetic Radio Frequency Interference
ER	Eastern Range
EREL	Established Reliability
ESD	Electrostatic Discharge
ETM	Environmental Test Matrix
FCA	Functional Configuration Audit
FMEA	Failure Modes and Effects Analysis
FOR	Flight Operations Review
FRR	Functional Readiness Review
FRB	Failure Review Board
FTA	Fault Tree Analysis
GDMS	Goddard Directives Management System
GDS	Ground Data Systems
GEVS	General Environmental Verification Standards

Abbreviation/ Acronym	DEFINITION
GFE	Government-furnished Equipment
GIA	Government Inspection Agency
GIDEP	Government Industry Data Exchange Program
GPR	Goddard Procedural Requirements
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
I&T	Integration and Test
IV&V	Independent Verification and Validation
IAC	Independent Assurance Contractor
IIRT	Integrated Independent Review Team
IPC	Association Connecting Electronics Industry
IRD	Interface Requirements Document
ISO	International Standards Organization
KHB	Kennedy Handbook
KSC	Kennedy Space Center
LRO	Lunar Reconnaissance Orbiter
LRR	Launch Readiness Review
M&P	Materials and Processes
MAE	Materials Assurance Engineer
MAR	Mission Assurance Requirements
MCM	Multi-Chip Module
MEB	Materials Engineering Board
MIL	Military
mm	millimeter
MOC	Mission Operations Center
MOR	Mission Operations Review
MPCB	Materials and Processes Control Board
MPCP	Materials and Processes Control Plan
MRB	Material Review Board
MSFC	Marshall Space Flight Center
MSPSP	Missile System Prelaunch Safety Package
MUA	Materials Usage Agreement
NASA	National Aeronautics and Space Administration
NCR	Nonconformance Reports
NDE	Nondestructive evaluation
NPD	NASA Policy Directive
NPR	NASA Procedural Requirement
NPSL	NASA Parts Selection List
NSPAR	Nonstandard Parts Approval Request
OHA	Operations Hazard Analysis
OSSMA	Office of Systems Safety and Mission Assurance

Abbreviation/ Acronym	DEFINITION
PAIP	Performance Assurance Implementation Plan
PAPL	Project Approved Parts List
PCA	Physical Configuration Audit
PCB	Parts Control Board
PCP	Parts Control Plan
PDR	Preliminary Design Review
PEM	Plastic Encapsulated Microcircuit
PER	Pre-Environmental Review
PFR	Problem Failure Report
PIL	Parts Identification List
PIND	Particle Impact Noise Detection
PRA	Probabilistic Risk Assessment
PSM	Project Safety Manager
PSR	Pre-Shipment Review
PSSSMA	Performance Specification Sheet for Space and Military Avionics
PWB	Printed Wiring Board
QA	Quality Assurance
QCI	Quality Conformance Inspection
QCM	Quartz Crystal Microbalance
QML	Qualified Manufacturer List
QMS	Quality Management System
QPL	Qualified Products List
RF	Radio Frequency
RFI	Radio Frequency Interference
RFA	Request for Action
RPP	Reliability Program Plan
RQMT	Requirement
SAM	System Assurance Manager
SAR	Safety Assessment Report
SCC	Stress Corrosion Cracking
SCD	Source Control Drawing
SCM	Software Configuration Management
SEL	Single Event Latch-up
SEU	Single Event Upset
SMD	Standard Military Drawing
SQMS	Software Quality Management System
SRO	Systems Review Office
SRP	System Review Program
SRR	Software Requirements Review
SRT	System Review Team
SSPP	System Safety Program Plan

Abbreviation/ Acronym	**DEFINITION**
STD	Standard
STS	Space Transportation System
TBD	To be determined
TID	Total Ionizing Dose
TML	Total Mass Loss
TRR	Test Readiness Review
TVAP	Technology Validation Assessment Plan
V	Volt
WOA	Work Order Authorization
WR	Western Range